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UNITED STATES
DEPARTMENT OF THE INTERIOR
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SAFETY DEVICE FOR THE INVERTED SIPHONS ON GATEWAY CANAL WEBER BASIN PROJECT, UTAH

Hydraulic Laboratory Report No. Hyd-391

ENGINEERING LABORATORIES

COMMISSIONER'S OFFICE
DENVER, COLORADO

March 3, 1955

FOREWORD

Hydraulic model studies on safety devices for the inverted siphons on the Gateway Canal, a part of the Weber Basin Project, Utah, were conducted in the Engineering Laboratories of the Bureau of Reclamation at Denver, Colorado, during the period of February to April 1954.

The final plans evolved from this study were developed through the cooperation of the staffs of the Canals Design Section and the Hydraulic Laboratory.

During the course of the model studies, Messrs. A. W. Kidder, J. A. Hufferd, R. D. Ridinger and W. N. Yehle and others of the Canals Design Section frequently visited the laboratory to observe the model tests and discuss the results.

The studies were conducted by T. J. Rhone under the direct supervision of A. J. Peterka.

Wild deer trapped in a canal just upstream from the entrance to an inverted siphon. Colorado-Big Thompson Project, Colorado.

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Laboratory Report No. Hyd-391
Hydraulic Laboratory
Compiled by: T. J. Rhone
Checked and
Reviewed by: A. J. Peterka

Subject: Safety device for the inverted siphons on Gateway Canal--Weber Basin Project, Utah

SUMMARY

The model studies described in this report were performed to develop a rescue device, to be placed at the entrance to an inverted siphon, which would provide easy escape for swimming or floating humans and animals that had inadvertently fallen into the canal.

Investigations were performed on several types of ramps placed over the siphon entrance and inclined into the flow. In each case the ramp was placed in or downstream from a specially designed transition. The preliminary investigations showed that unless the approaches and the device were properly designed, vortices and eddies in the siphon entrance were more violent and dangerous than in an unprotected entrance. To provide satisfactory performance it was found necessary to direct the flow toward the center of the channel by converging the side walls to eliminate the dead water areas where vortices and eddies formed.

To provide optimum performance it was necessary to replace the solid ramp of the preliminary design with a ramp composed of five steps having part of the riser of each step left open to allow passage of the surface flow, Figure 9. Proper arrangement of the structure resulted in a very effective safety device with excellent flow conditions, Figure 10, which was recommended for field construction.

INTRODUCTION

Operation of various canal systems indicated there was a need for a device that would provide a measure of safety at the entrance to inverted siphons (see frontispiece). To satisfy this need, model studies were performed to develop a safety device for use on the Gateway Canal, Weber Basin Project, Utah. It was originally intended to construct the devices on only two of the inverted siphons of the canal for the dual purpose of preventing the bodies of dead animals from clogging the siphon and also to permit swimming or floating animals or humans to escape before being swept into the siphons. These two installations were to be field tested before additional devices were constructed; however, when the model studies showed that the safety devices were reliable, would provide a measure of safety for humans as well as animals, and were not expensive to construct, they were adopted for all seven inverted siphons on the canal.

THE MODEL

A scale ratio of 1:12.22 was chosen for the model so that an available part of an existing canal model and siphon pipe could be used for these tests. The model included a short section of the canal upstream from the siphon, constructed of plywood, the transition between the canal and the entrance to the inverted siphon constructed from clear plastic, Figure 1. The ramps or safety devices were made of waterproofed wood. Structure No. 2, Figure 1, was constructed later and was not in the model for the first tests.

Water was supplied to the model through the permanent laboratory supply system and measured with a 6-inch venturi meter. The flow depth in the canal was controlled by a slide gate placed on the downstream side of the plastic pipe.

THE INVESTIGATION

All devices were first tested at the maximum discharge of 700 cfs with the flow depth in the canal maintained at 6.90 feet or normal depth at this discharge. The performance of the device being investigated was judged by the velocity and direction of the surface flow as indicated by floating confetti and a partially submerged model "deer," and by the direction of the subsurface flow as indicated by dye streams injected into the flow. If the device being tested caused dangerous eddies, large vortices, or other poor flow conditions, or if the flow did not carry the "deer" to safety on the rescue device, the design being investigated was considered unsatisfactory. Devices which showed promise or operated well were further tested at 350 cfs and normal depth 4.85 feet.

Preliminary Design

The preliminary rescue device consisted of a sloping solid ramp placed in the specially shaped transition upstream from the siphon entrance, Figure 2.

The flow appearance with this device was very poor. Two large vortices formed at the upstream edge of the ramp that were of such magnitude that floating or partially submerged objects in the canal were swept into one or the other of the vortices and immediately carried down into the inverted siphon. Figure 3 shows the flow appearance with this safety device. Also shown is the flow appearance at the siphon entrance with the safety device removed. A comparison of these pictures shows that the preliminary safety device produced a flow condition at the siphon entrance more dangerous than was present without a safety device.

Without the safety device the flow up to the siphon entrance was very smooth with only very slight local disturbance directly over the entrance. Floating objects were carried to the headwall of the siphon entrance where they were held; however, since the wall was vertical, there was no chance for escape. Partially or totally submerged objects on the other hand were immediately swept down into the siphon barrel.

The violent downward flow currents at the siphon entrance indicated that it might be necessary to separate the safety device and the siphon entrance structure in order to develop a satisfactory safety device. It was also felt that a greater flow area between the ramp and the transition floor was necessary. The next tests were made to determine the area requirements.

Structure No. 2

The second safety device was a separate structure entirely removed from the siphon entrance, Structure No. 2, Figure 1. About 100 feet upstream from the inverted siphon a wide rectangular basin was built into the canal and connected to the canal by means of short transitions, Figure 4. A solid escape ramp, inclined into the flow so that floating or partially submerged objects would be washed up on it, was placed over the rectangular section so that the area under the ramp was equivalent to that of the wetted canal section.

In operation, this arrangement was not satisfactory since the ramp caused several small vortices to form along each side wall upstream from the ramp, Figure 5A. There were also eddy currents that forced objects, floating anywhere except down the exact center, into one or the other of the vortices.

Since this device was unsatisfactory and it appeared that improvement could only be obtained by increasing its size and the length of the approach transition, it was decided to continue development of the device at the siphon entrance.

Structure No. 3

The third structure was located at the siphon entrance and differed from the preliminary design in that the transition between the canal and the siphon entrance was made longer and was divided into two sections, Figure 6. In the upstream section the canal floor dropped about 6 feet and the side slopes, while converging slightly, changed from a 1-1/2:1 slope to vertical in a length of 30 feet. The second section, about 20 feet in length, had only a slight bottom slope and the vertical side walls converged to the siphon entrance, Figure 6. The safety device, located in the downstream or second section, consisted of a solid ramp placed over the siphon entrance and sloped downward into the flow, so that it could intercept a floating or partially submerged object. It was thought that by separating the two features, (1) the transition between the canal and the siphon entrance, and (2) the safety device, that the action of one would not interfere with the action of the other and that a satisfactory design would result.

Flow through this device was definitely improved over that previously obtained but still was not entirely satisfactory, Figure 5B. Although a floating or partially submerged object was carried up onto the ramp, there was a reverse flow along both walls from the safety device upstream, and unless the object was able to walk up the ramp immediately after being deposited thereon, the reverse current carried it upstream to re-enter the downstream flow again. The reverse current also caused vortices to form at the upstream edge of the ramp and the chances were about even that an object washed off the ramp by the reverse current would be trapped in a vortex rather than carried back onto the ramp.

The reverse flow at the safety device was caused partly by the solid ramp. The surface flow passed onto the ramp and not being able to continue downstream was forced to turn and flow against the current along each wall.

It was believed that this reverse flow could be utilized in providing an effective safety device. Vertical converging guide walls extending only sufficiently deep to control the flow at half discharge were added to the structure so that the current passed along the inside faces of the walls and turned to flow upstream around the downstream end of the wall. Floating objects and the model deer were carried behind the wall and thus could conceivably escape if a ramp could be devised, Figure 7.

Experiments with this arrangement showed that in order to maintain the reverse flow a partial bottom opening between the guide walls and the transition had to be provided. Difficulties in developing a practical escape ramp and maintaining the bottom opening at the same time combined with the general complexity of the structure made this device impractical.

Tests were continued on the basic features of Structure No. 3, however, to prevent or minimize the reverse flow by perforating or removing the middle portion of the ramp to allow the surface flow to continue downstream.

With the center portion of the ramp removed the safety device consisted of a ledge around the outer edge of the transition. Performance was unsatisfactory.

The slight improvement in the flow conditions when the perforated ramp was used indicated that a ramp with larger perforations or openings might perform better. In order to provide larger openings which would not in themselves become a hazard to animals or humans, the solid ramp with holes was replaced by a stepped ramp, which in effect was a stairway. The steps had 5.5-foot treads and 1-1/4-foot risers. Six inches of the risers were left open to allow flow passage, Figure 8.

Figure 5C shows the flow appearance with the stepped ramp. The operation was very good and in the majority of the trials a floating or partially submerged object was carried to safety by being deposited well up on the stepped ramp. However, there was still a slight return flow along both walls that sometimes returned the object into the approaching flow. It was found that this undesirable feature could be corrected by using converging guide walls to direct the surface flow toward the center of the stepped ramp.

Recommended Structure

The recommended structure combined the best features and modifications of Structure No. 3, including simplification of certain features to eliminate unusual field construction problems. The recommended structure consisted of two separate sections, an upstream and a downstream section, Figure 9.

The upstream section, 30 feet long, contained vertical walls on each side that converged from the 35-foot top width of the canal to the 11-foot siphon entrance width; the floor dropped about 7 feet in elevation on a trajectory curve; and at the intersection of the side walls and the floor a variable height fillet was used on each side to complete the transition from the sloping canal banks to the vertical wall of the downstream section.

The downstream section of the recommended structure was about 12 feet long and had vertical side walls set 11 feet apart, with the steps of the safety device spanning this opening. Each of the five steps had a 2-1/2-foot tread and a 15-inch riser. The lowest step of the ramp was 8-1/2 feet above the floor at its upstream edge, Figure 9.

The recommended structure was checked at the maximum discharge of 700 cfs and at half discharge of 350 cfs. The flow appearance was very good at both discharges, Figure 10, indicating that the device would operate satisfactorily for the most prevalent discharge range. The performance of the structure was also checked by means of floating confetti and by dye streams injected into the flow at varying depths. The confetti showed that the surface flow lines were very smooth as the flow approached the inverted siphon and the safety device caused no objectionable vortices or other eddy currents. The flow lines for the 700 cfs discharge are shown by the white confetti traces in the picture on the right side of Figure 10. The subsurface currents, checked at the two discharges by means of dye streams injected into the flow at varying depths, also showed that the flow approaching the inverted siphon was very smooth with no objectionable eddy currents.

In making the tests on this structure, objects and the model deer were usually thrown into the canal a short distance upstream from the safety device so that they were floating or only partially submerged when they passed through the test section. The deer or other objects were always carried to safety on the ramp. It was found, however, that the deer, when pushed off the side wall directly upstream from the ramp, sometimes penetrated the top current which ordinarily carried him to safety, and was swept into the siphon by the undercurrents.

It is very unlikely that an animal would fall into the canal at this particular spot. It is more likely, however, that small boys seeking a swimming hole might be deceived by the quiet surface water and dive into the water from the top of the wall. To prevent accidents of this type a short length of high fence extending about 30 feet upstream from the ramp should be installed.

Another auxiliary protective device, this one tested in the model, consisted of a grid placed across the flow opening beneath the ramp at the upstream edge of the lower step. The grid had 6-inch openings between 1/2-inch bars and was placed either vertically or tilted slightly downstream. The tests showed that the grid did not interfere with the flow and that the mesh could become about 15 percent clogged with debris without affecting the usual flow patterns. This device need not be installed unless field experiences show the need.

To obtain maximum benefit from the safety device the canal should flow at or near the normal depth. Model studies showed that the device was very satisfactory for all discharges greater than 200 cfs if the normal depth in the canal was maintained; however, if this depth was decreased about 1 foot the operation, while still adequate, was not completely satisfactory. For discharges less than 200 cfs, the water surface was below the bottom step of the device, however, under most conditions the flow in the canal was sufficiently shallow that it was felt there was slight danger of humans or animals not being able to maintain their footing.

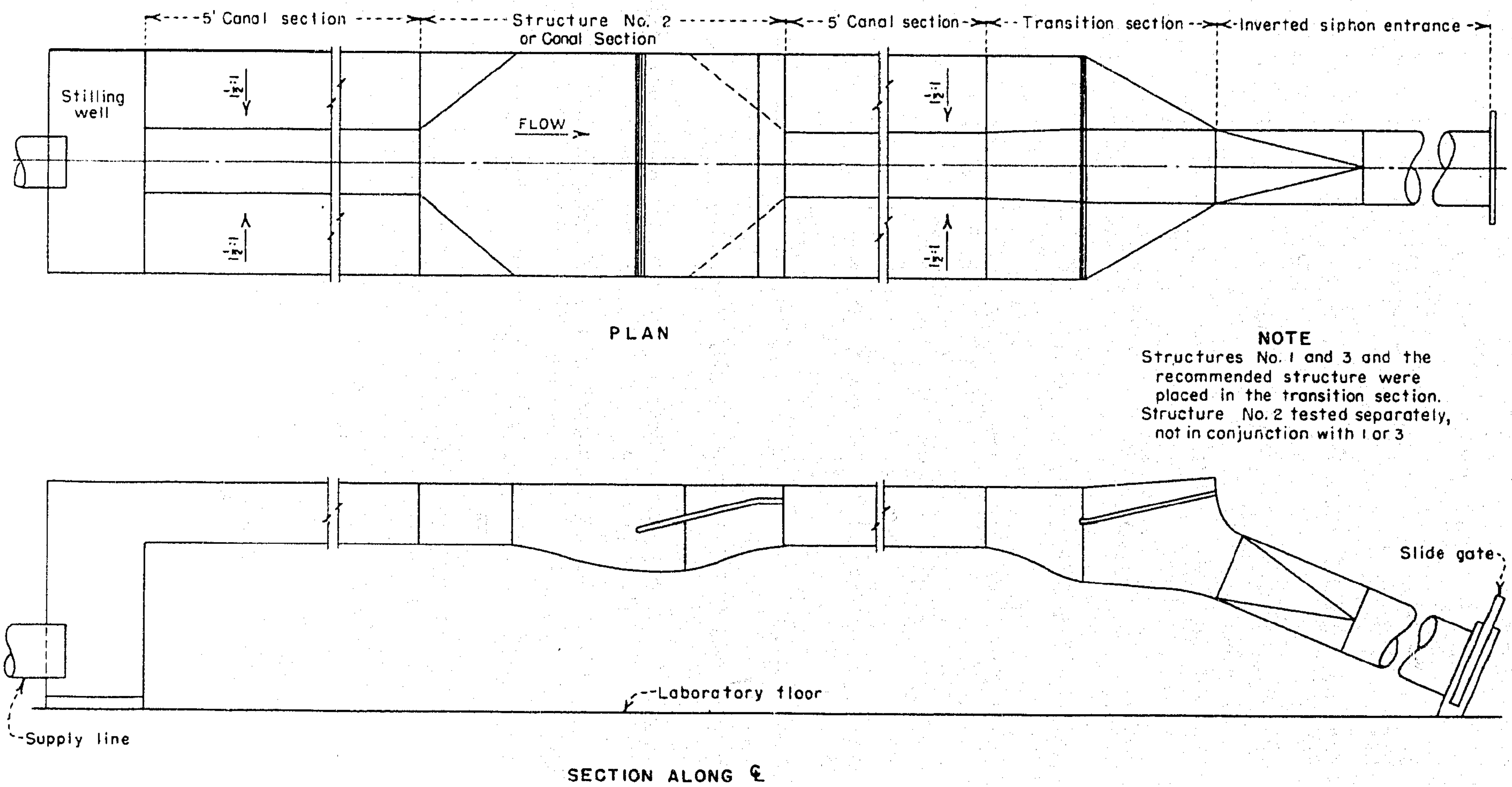
Alternate Recommended Structure

To simplify the concrete form work for the field structure an investigation was made with the curved surfaces of the bottom end of the fillet in the upstream section replaced with plane surfaces, Figure 11. Operation at maximum discharge showed that the flow conditions at the structure were satisfactory although the water surface was rougher than it was in the recommended structure. When the open portion of the step risers were partially blocked, there was a tendency for vortices to form at the upstream edge of the safety device. On the basis of these tests, it was decided that the curved surfaces in the structure were helpful in providing good operating conditions.

Modified Design

After completion of the above-described tests and in the course of making the construction drawings, the designers felt that a streamlined and warped transition which had a uniform area change with respect to length would provide better performance and the laboratory was asked to test the transition shown on Figure 12. The flow appearance with this transition was similar to that obtained in the alternate recommended design. The modified structure was considered satisfactory but because of the decreased cross sectional area in the streamlined transition the flow was somewhat rougher than that for the recommended structure.

An additional test was made on the modified structure to show the velocity distribution at the upstream edge of the safety ramp. Figure 13 is a plot of the velocity distribution for a discharge of 700 cfs at normal depth. The distribution was comparatively uniform with the highest velocity occurring near the center of the cross section. The velocity decreased uniformly toward the surface and toward the floor from the center.



GATEWAY CANAL MODEL STUDIES
INVERTED SIPHON SAFETY DEVICE
SCHEMATIC MODEL LAYOUT

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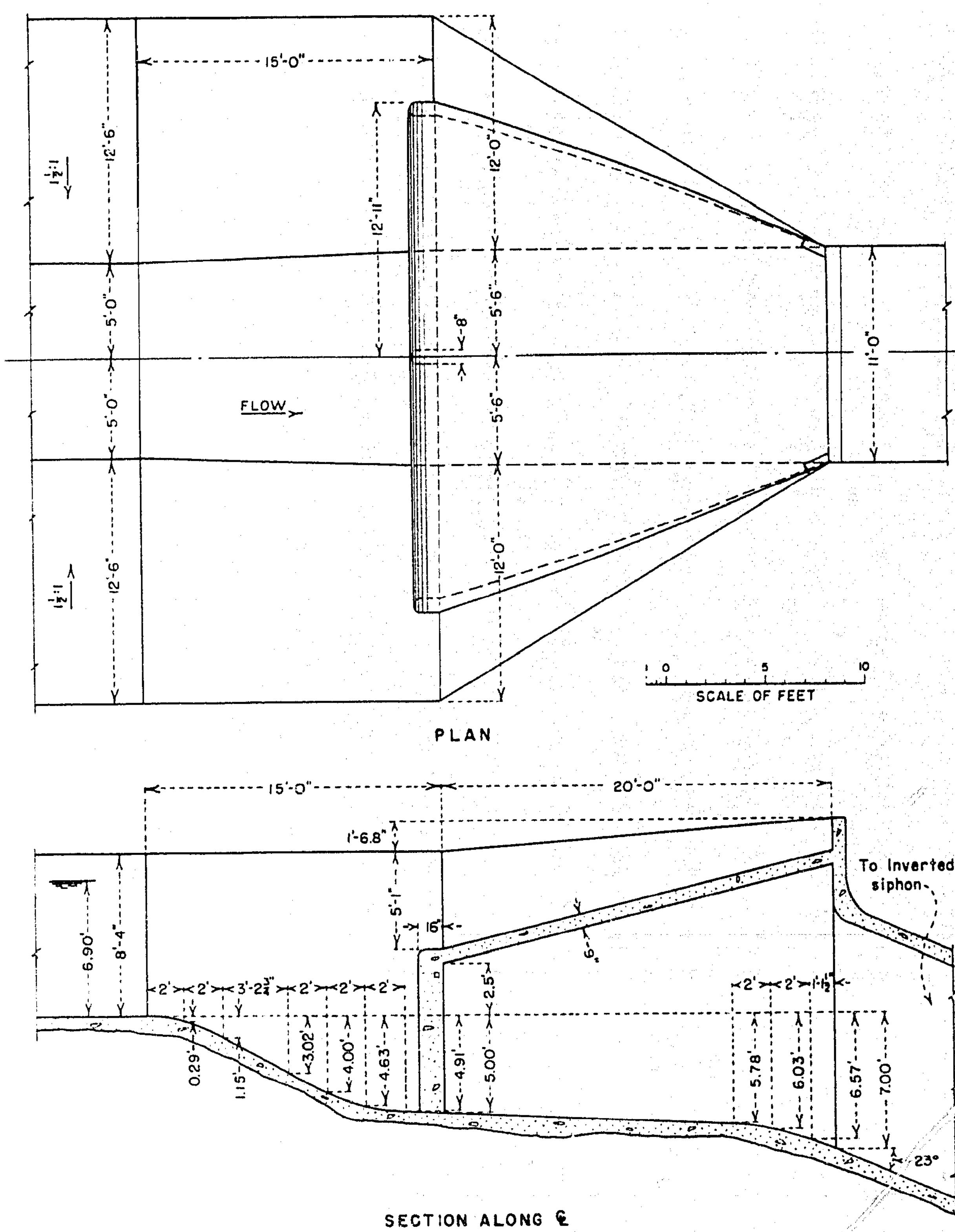
FIGURE 1
REPORT HYD 391

FIGURE 2
REPORT HYD 391



GATEWAY CANAL MODEL STUDIES
INVERTED SIPHON SAFETY DEVICE
PRELIMINARY DESIGN

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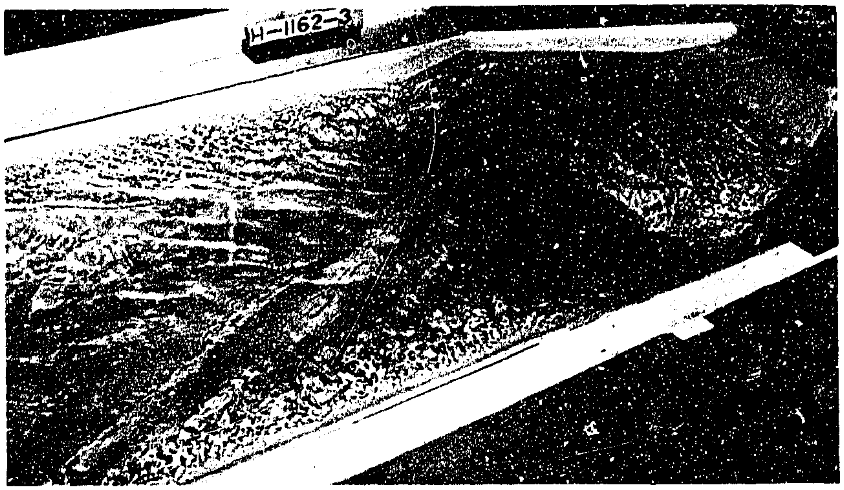
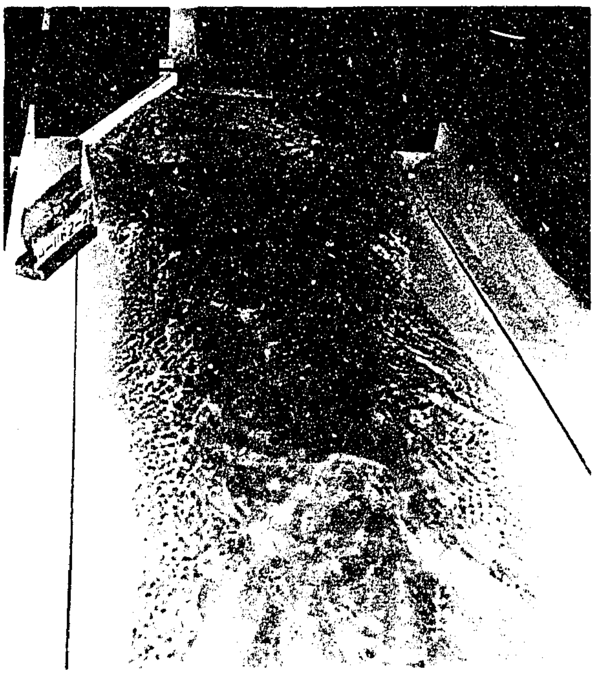
Figure 3

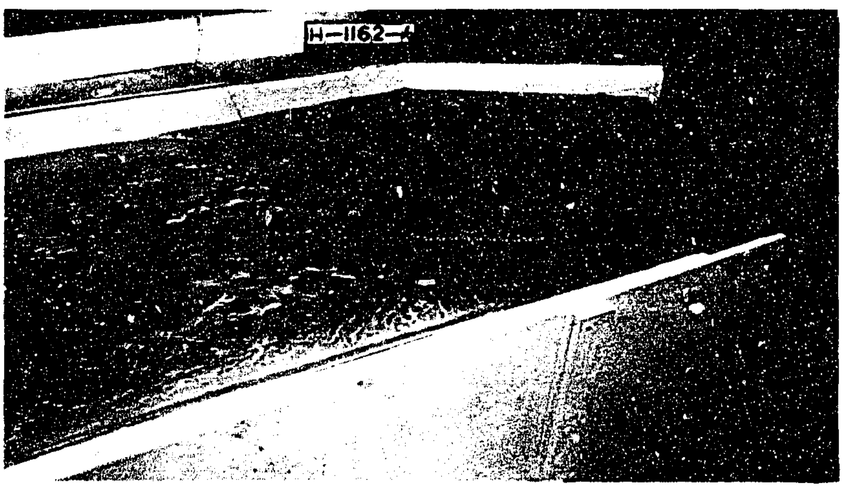


Vortices
form
over
ramp



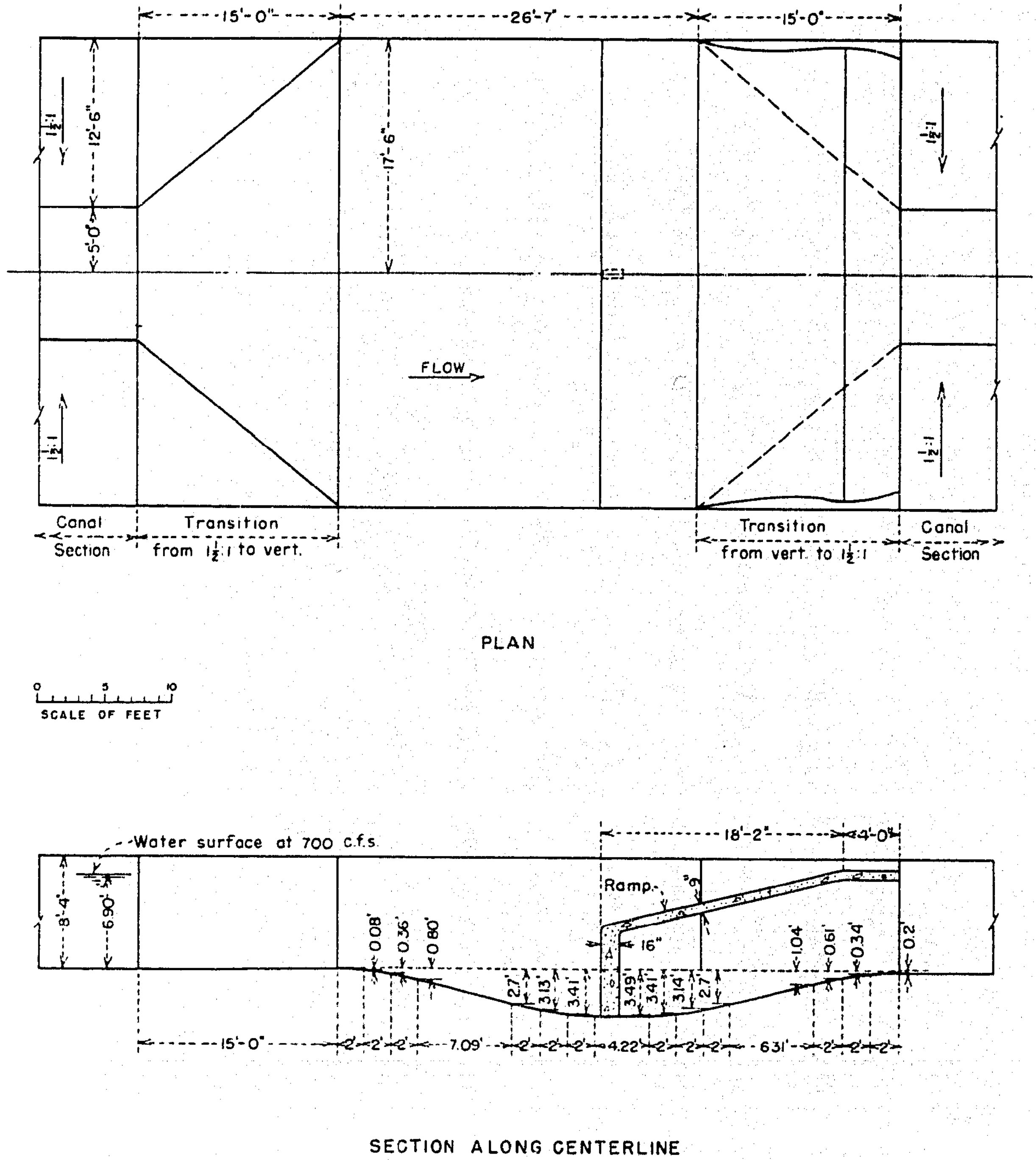
Undulating canal surface
induced by vortex action

Solid ramp in place

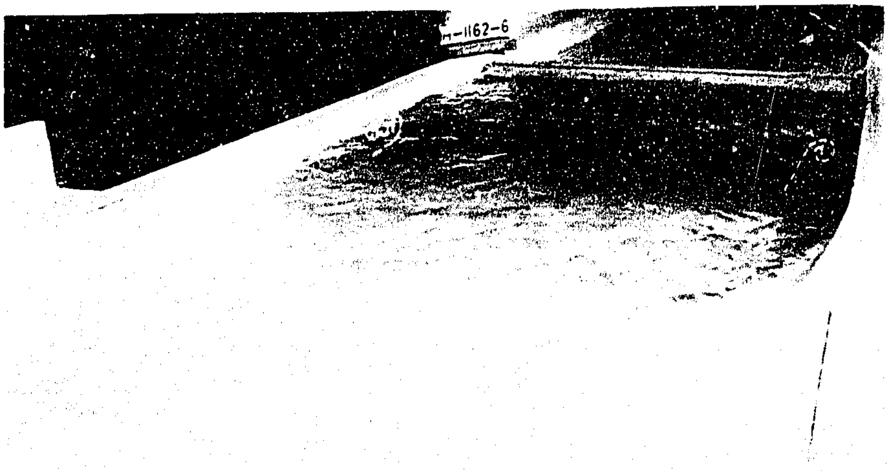


Unprotected siphon entrance
Ramp removed

GATEWAY CANAL MODEL STUDIES
Safety Device for Inverted Siphon
Flow in preliminary design at 700 cfs

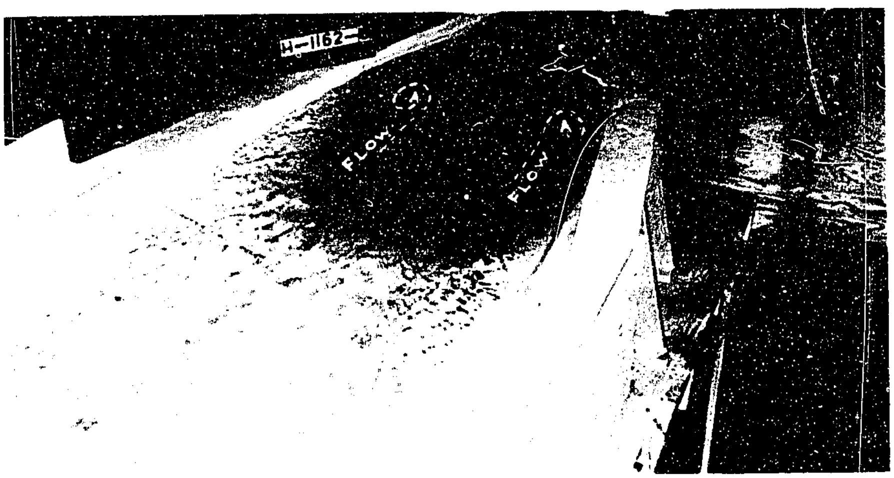


GATEWAY CANAL MODEL STUDIES
INVERTED SIPHON SAFETY DEVICE
STRUCTURE NO. 2



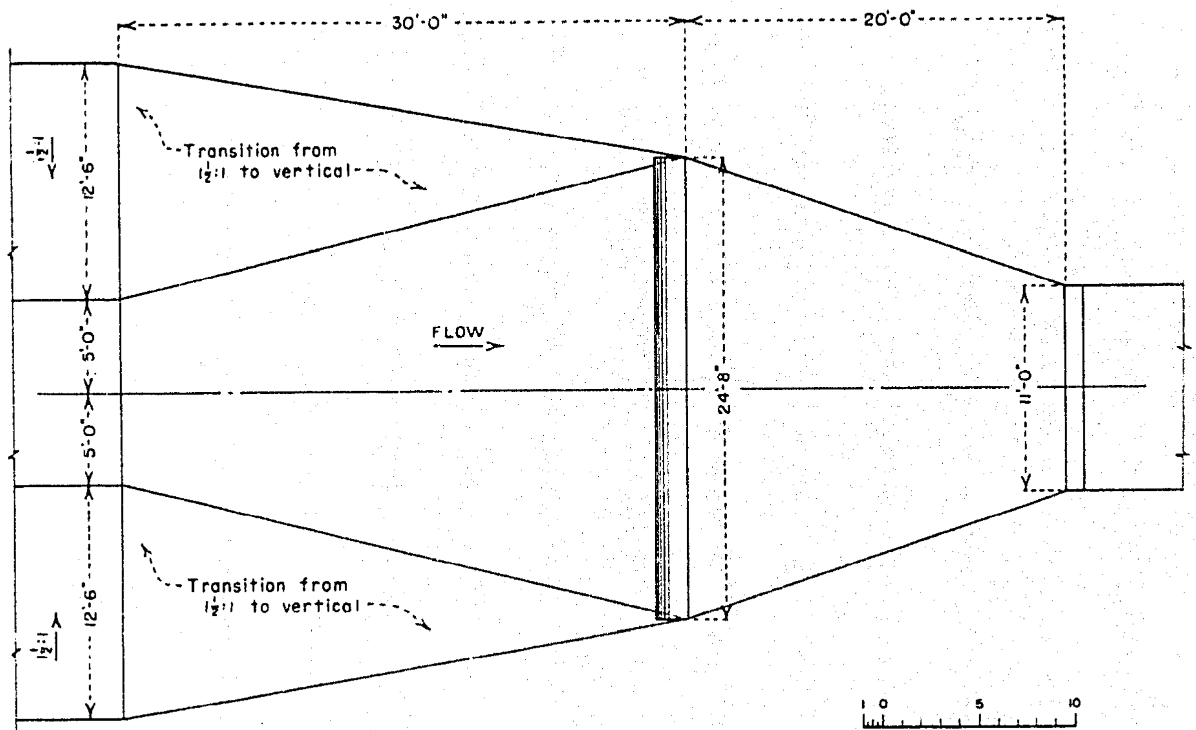
A. Structure No. 2 Solid ramp in canal section

B. Structure No. 3 Solid ramp at siphon entrance

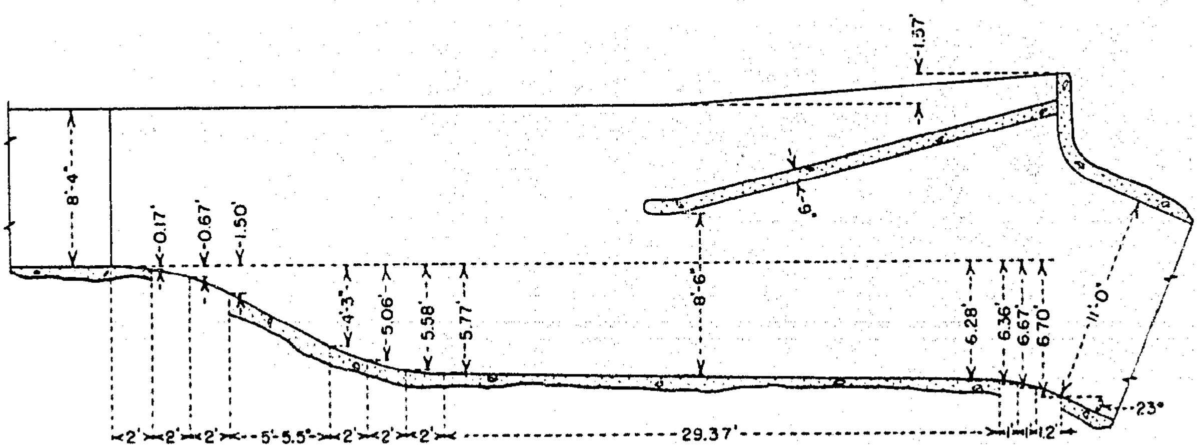


C. Structure No. 3 Stepped ramp at siphon entrance

GATEWAY CANAL MODEL STUDIES
Inverted Siphon Safety Device
Flow appearance in structures nos. 2 & 3 at 700 cfs

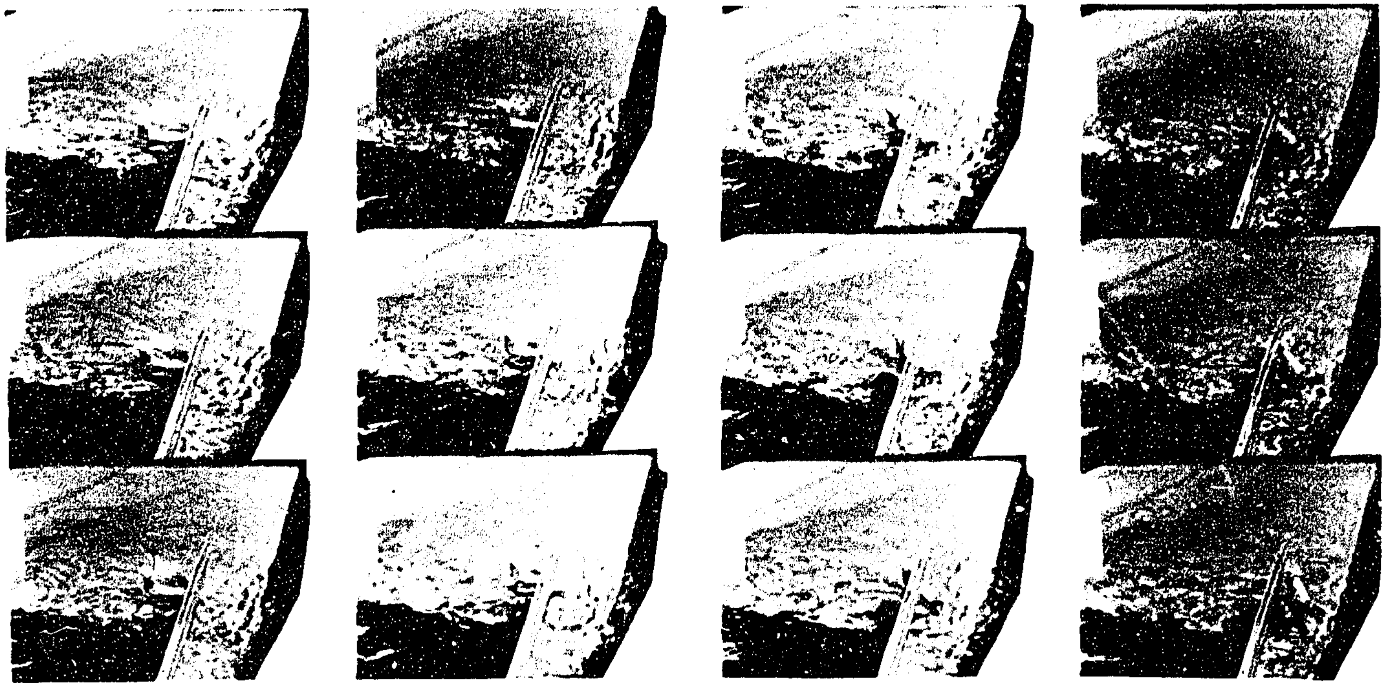


PLAN

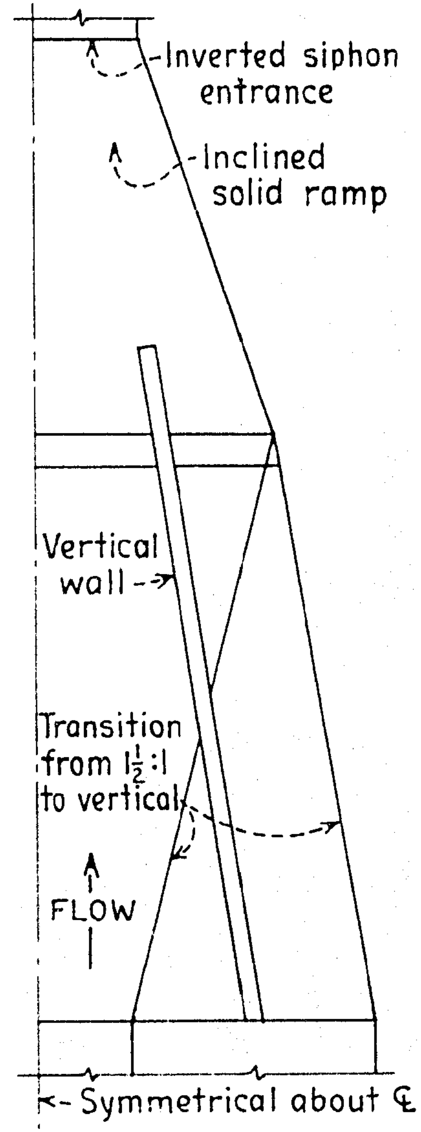


SECTION ALONG ℄

GATEWAY CANAL MODEL STUDIES
INVERTED SIPHON SAFETY DEVICE
STRUCTURE NO. 3 WITH SOLID RAMP



The action of the "deer" being swept around the wall is shown in this series of pictures enlarged from motion pictures of the model studies. The order of pictures is from the top down in each row, rows left to right. The wall is near the center of each frame; flow from the bottom up.



HALF PLAN

GATEWAY CANAL MODEL STUDIES
Inverted Siphon Safety Device
Guide walls in structure No. 3

FIGURE 7
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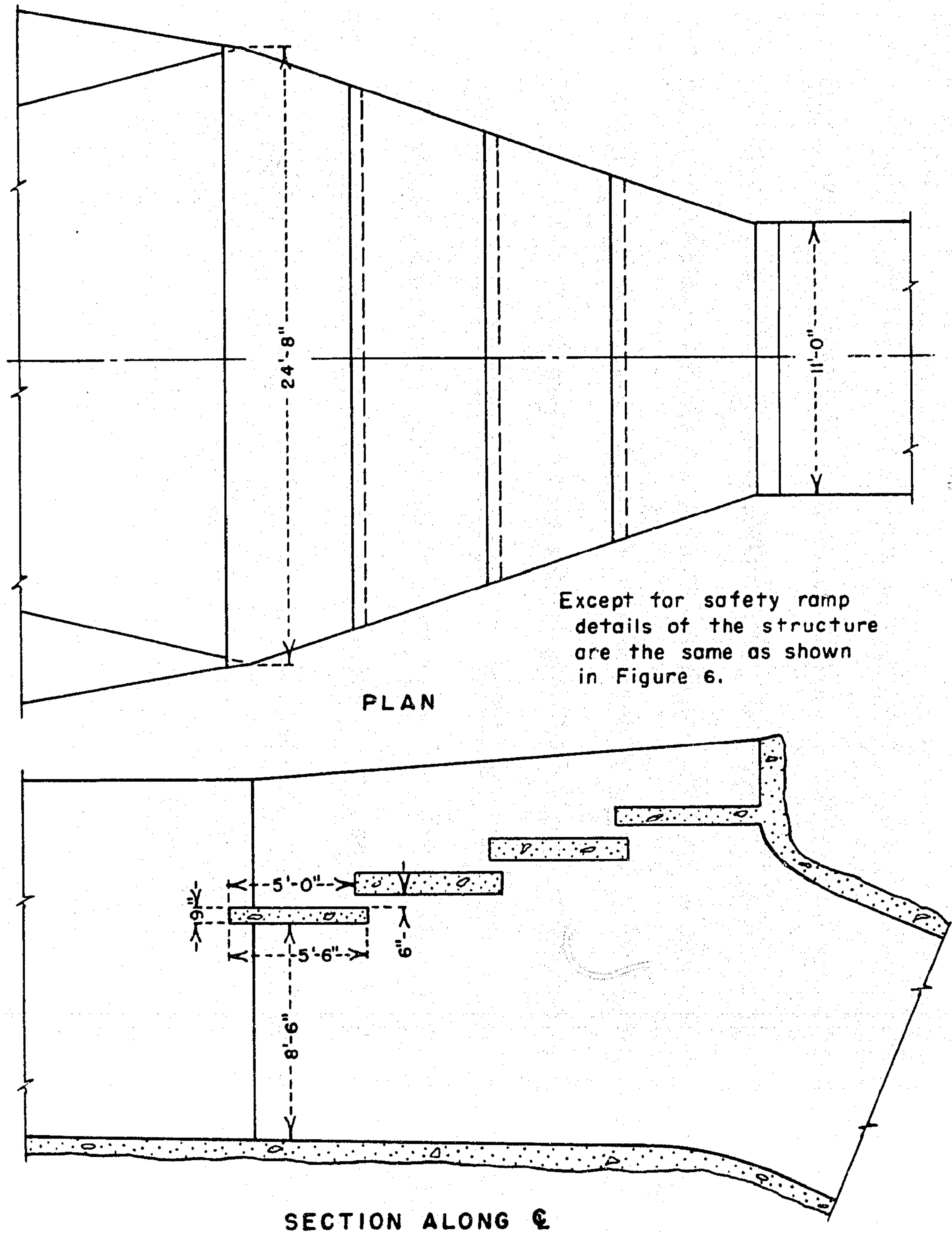
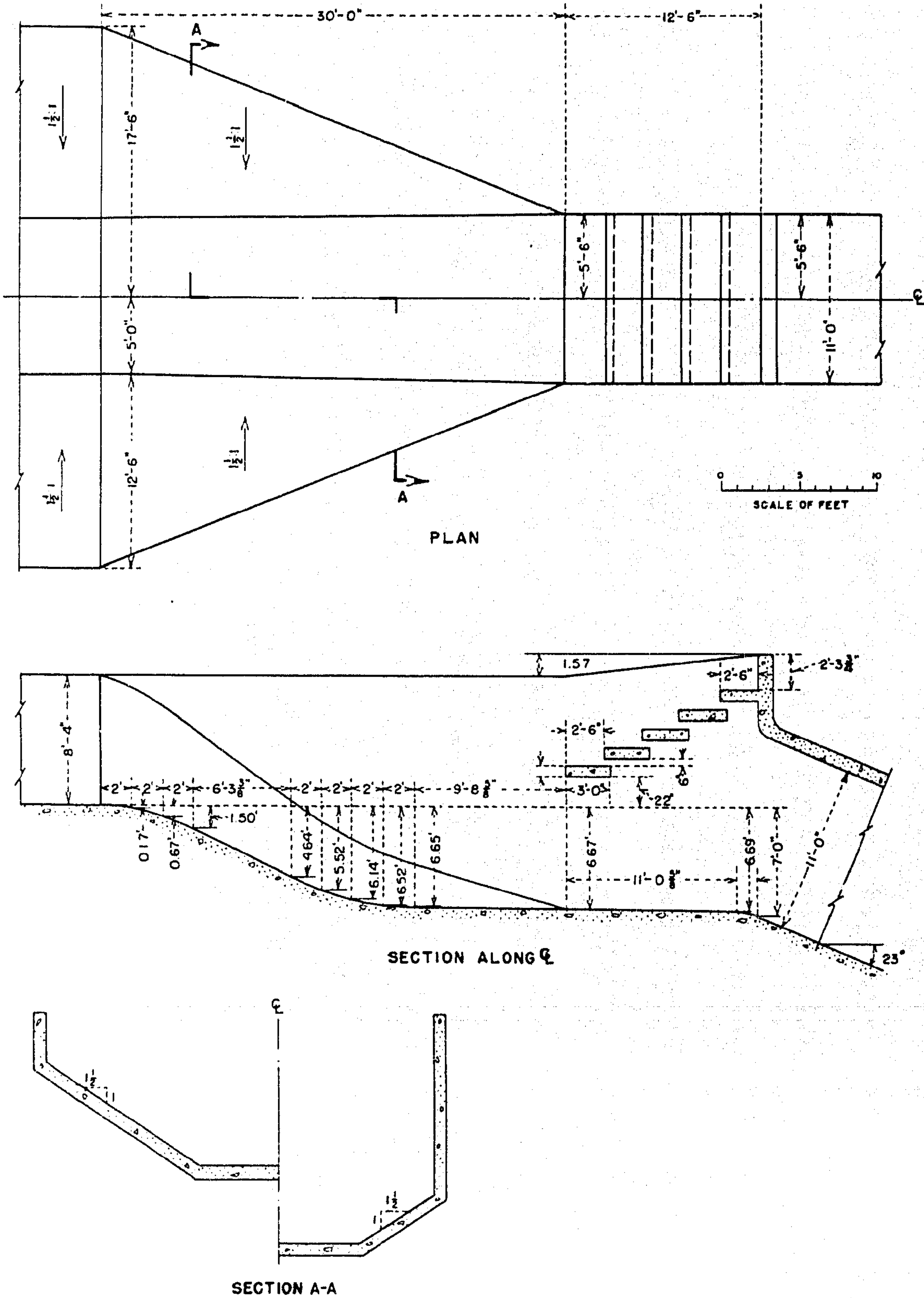


GATEWAY CANAL MODEL STUDIES
INVERTED SIPHON SAFETY DEVICE
STRUCTURE NO. 3 - WITH STEPPED RAMP

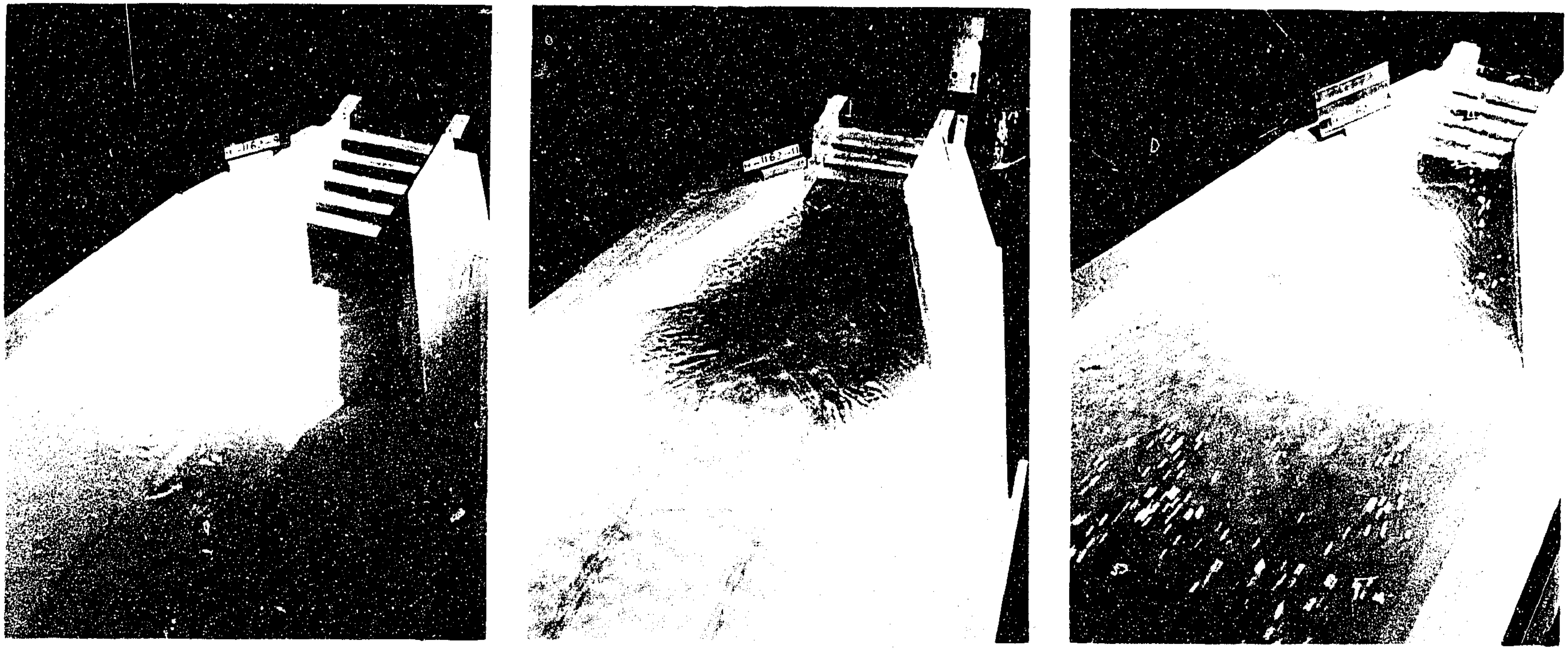
FIGURE 9
REPORT HYD. 391



GATEWAY CANAL MODEL STUDIES

INVERTED SIPHON SAFETY DEVICE

RECOMMENDED DESIGN



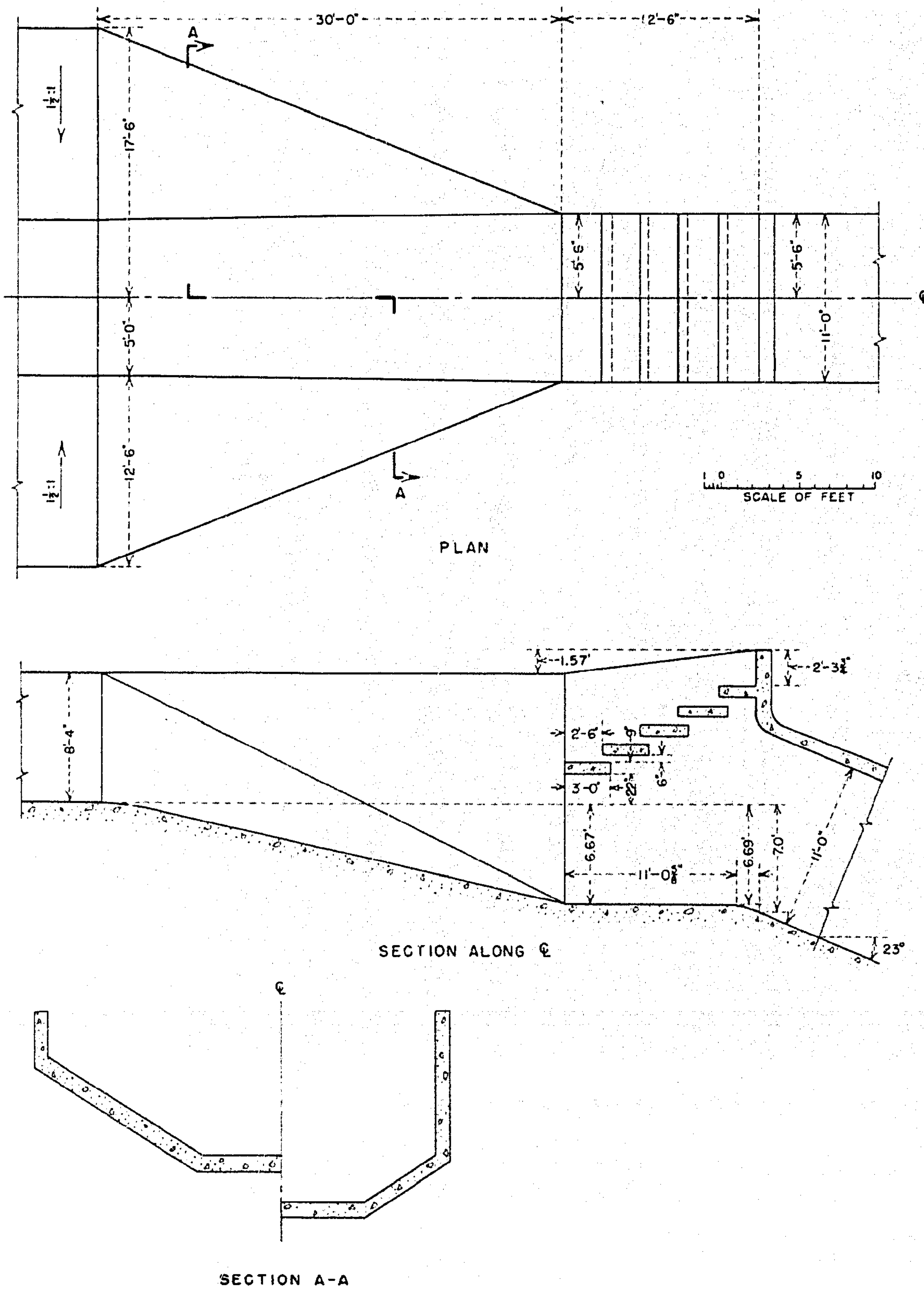
No flow

350 cfs

700 cfs Note model "deer" carried to safety on stepped ramp

GATEWAY CANAL MODEL STUDIES
Inverted Siphon Safety Device
Recommended design

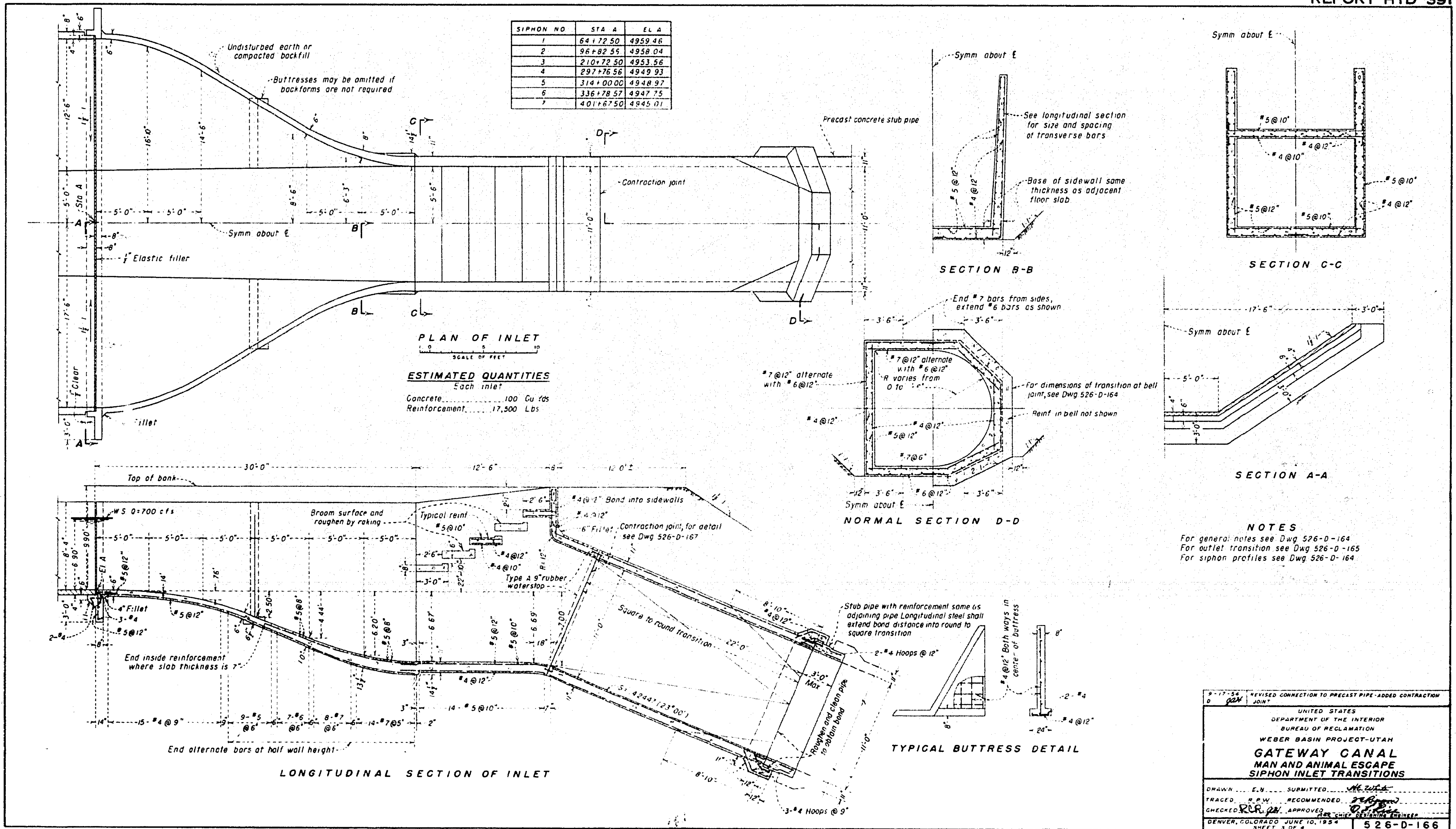
Figure 10



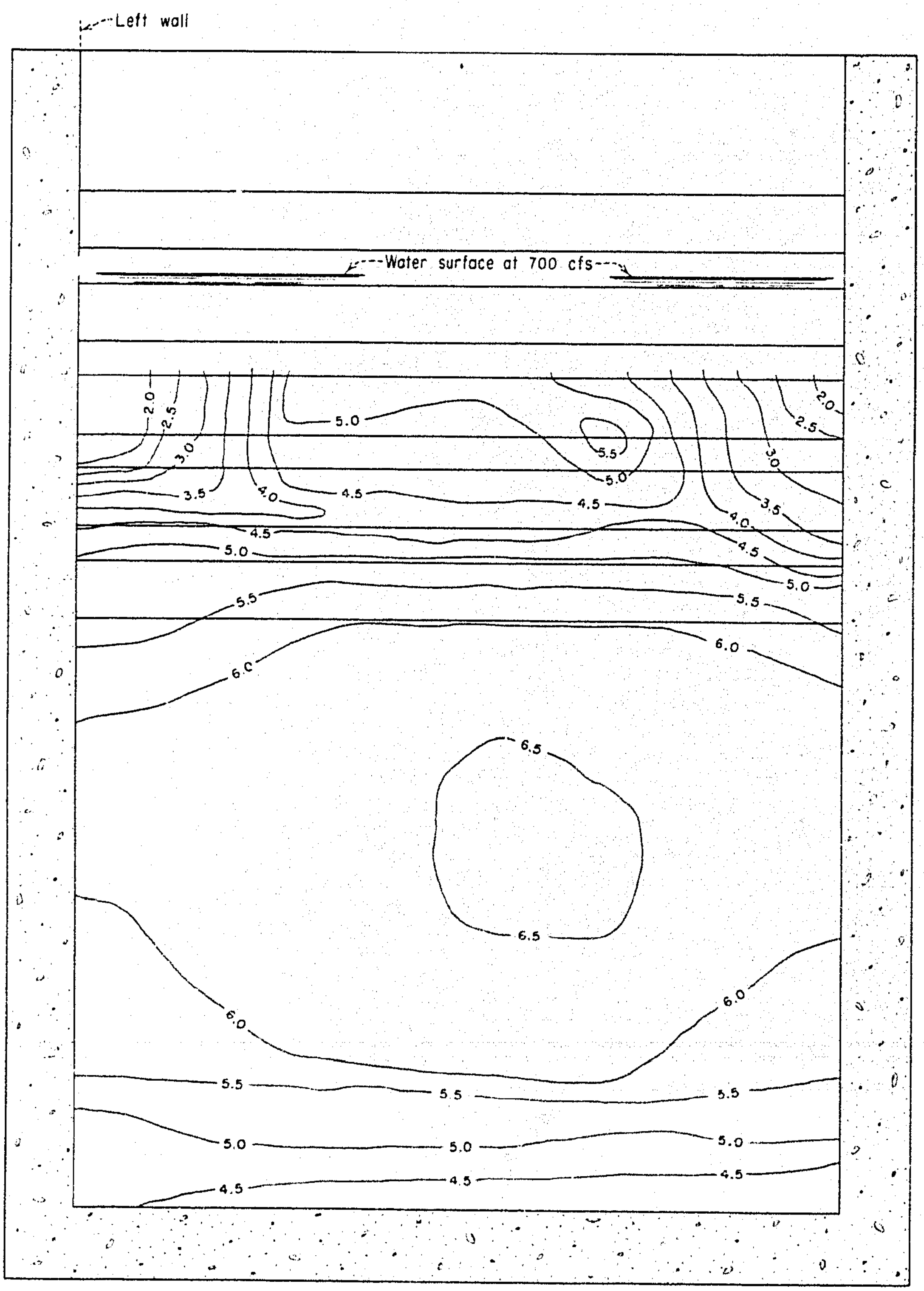
GATEWAY CANAL MODEL STUDIES

INVERTED SIPHON SAFETY DEVICE
ALTERNATE RECOMMENDED DESIGN

FIGURE 12
REPORT HYD 391



SIPHON NO	STA A	EL A
1	64+72.50	4959.46
2	96+82.55	4958.04
3	210+72.50	4953.56
4	297+76.56	4949.93
5	314+00.00	4948.97
6	336+78.57	4947.75
7	401+67.50	4945.01



VELOCITY DISTRIBUTION IN CHANNEL CROSS SECTION
AT UPSTREAM EDGE OF SAFETY RAMP
(Looking downstream)

GATEWAY CANAL MODEL STUDIES
INVERTED SIPHON SAFETY DEVICE
MODIFIED DESIGN
VELOCITY DISTRIBUTION

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